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TECHNICAL NOTE

A NURSERYMAN'S PRIMER ON GREENHOUSE COMPUTERS

INTRODUCTION

Traditional greenhouse climate control and monitoring systems are rapidly becoming obsolete because of the increasingly widespread application of microprocessor technology. For the first time, the computational power delivered by a good personal computer is more than sufficient to maintain not only the greenhouse environment but other associated functions, as well.

When reference is made to a "nursery" or "greenhouse" computer, one of two functional types is being implied: a machine whose configuration and software (programming) are intended to keep records of inventory, scheduling and accounting, or a terminal plus peripheral devices whose purpose is to control and record greenhouse climate. This note is concerned with the latter type. (However, with the development of microcomputers capable of running more than one program simultaneously - multi-tasking - future machines will perform both functions. A stock inventory program, for example, could be called up and run without having to stop or interrupt the climate controller/datalogger running in the background.)

A number of different climate computer systems with proven track records for performance are already available. Each has different strengths and operating characteristics. All, however, can be comparatively assessed on the basis of the following general criteria (Halamka 1984):

- What features does the computer have and how does it compare with its competitors?
- What is the system performance - i.e., are the features combined and packaged in such a way as to be useful and efficient at your particular nursery?

NURSERIES ■

PLANTATIONS

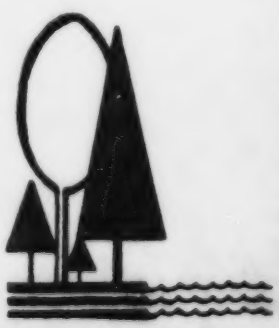
SILVICULTURE

UTILIZATION

ECONOMICS

TREE IMPROVEMENT

INSECTS AND DISEASES



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- Is the documentation sufficiently clear and readable to allow a novice to use (and understand) the system? Conversely, is there enough depth to the information to allow an advanced user to fully exploit the features and power of the computer?

- Does the vendor or the manufacturer provide after-sales support? Are they capable of responding immediately to emergencies, even at a distant nursery? Equally important, is there a commitment to update, upgrade and/or customize, routinely and at a reasonable cost, as the user gains experience and the requirements expand and become more sophisticated?

The above criteria are critical for most nurserymen, especially those unfamiliar with computers and, perhaps, situated in a remote locale.

SYSTEM DESCRIPTION

A climate computer is seldom contained in an integrated package, unlike the home computer. A number of different components, which may be widely separated physically, are required to connect (interface) computing power with the greenhouse and outside environment. In some systems, more than one computer may be present (Fig. 1).

Within each greenhouse, sensors for temperature, humidity, light intensity, soil moisture and conductivity, and CO2 may be present, wired in to the computer. A weather station with light, temperature, precipitation, and windspeed sensors is usually present. Temperature and pressure sensors may also be placed in the heating plant and distribution lines.

Communication with the computer(s) in which the control and monitoring program resides - and there may be more than one of these units - is usually done using another microcomputer. Off-the-shelf units (Commodore, IBM-PC, Apple, etc.) are often used for this purpose. These units permit programming in high-level languages, like BASIC or FORTRAN, and, thus, make it easier for the nursery operator to use the system.

Often it is not even necessary to know how to program. Usually, the manufacturer provides the programming for the routine greenhouse operations, which is totally "transparent" to the nurseryman, requiring no knowledge of computer language. The input and output functions are put into a "menu" format, in which the computer asks questions or gives explicit instructions, allowing the nurseryman simply to enter the numerical data representing setpoint temperatures, timing, or whatever other parameters required, in response to specific questions appearing on the terminal screen.

SYSTEM CONTROL CAPABILITIES

This section gives an overview of the capabilities found in control systems now on the market. Not all systems will have all the capabilities described here; some have many in addition to those of interest in a

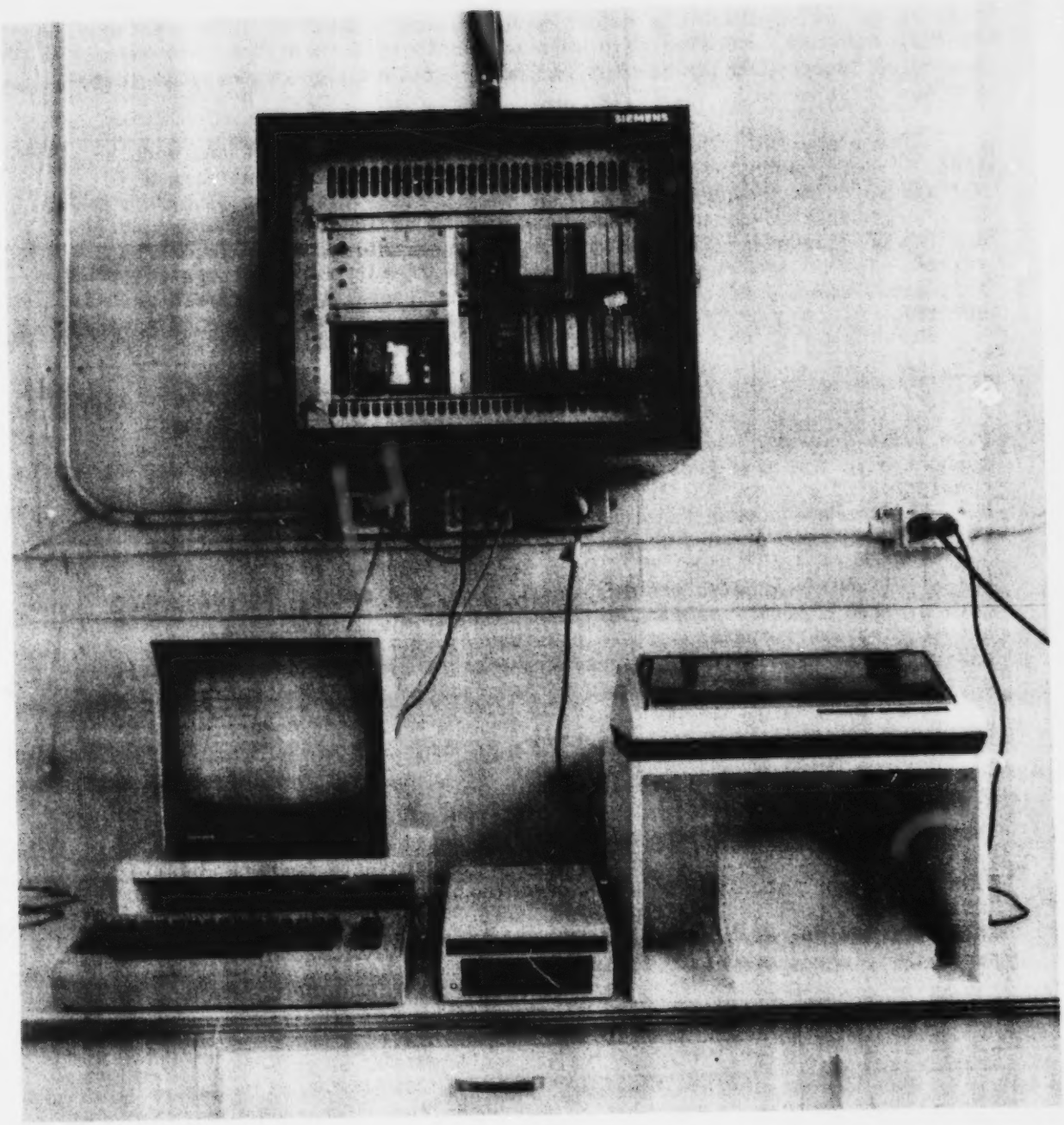

Figure 1. Dedicated greenhouse climate control computer.

typical reforestation nursery (for instance, a variety of ventilation functions dedicated to modulated side and/or ridge vent systems). Systems featuring comprehensive software - an all-in-one package containing programming sufficient to run almost any nursery, regardless of configuration, as opposed to a tailor-made package written exclusively for a specific nursery - usually have ways of turning off functions which are unused or inappropriate, so that the nurseryman can ignore features that are not of interest.

There are two major types of control functions: on/off and modulation. On/off control is accomplished by the computer transmitting a voltage which may energize a relay or toggle some other type of on/off device. Modulated control is used to control devices where the amount of opening or closure is important - for instance, sidevents or motorized valves. The controlling signal is still a voltage, but a voltage which is present for a predetermined period of time (or a series of voltage pulses).

Heating

All types of heating are supported: circulation pumps, finned pipe, unit heaters, and root zone systems. More than one type can be supported in the same growing area, and multi-staged heating systems consisting of a number of independently controlled and settable subsystems are a common feature. Heating setpoints may be controlled according to time of day, light level or even outside temperature (for energy conservation). During a 24 h period, a number of different setpoints are programmable (e.g., dawn, dusk, and several periods for both day and night). Ramping of temperature, i.e., the slow transition between two set temperatures, is possible. One increasingly common option is the capability to modulate the night temperature on the basis of the integrated light amount from the previous day (or several days).

Heating Plant

An important programmable function is boiler water temperature. It can fluctuate according to both the differential between indoor (setpoint) and outdoor temperature as well as ambient daytime light levels, or a combination of both, in order to conserve energy. Heating plants with more than one boiler can automatically cascade the firing of individual units according to demand. Pipe temperatures in individual growing zones can also be varied, according to the same control parameters, using motorized mixing valves. More heating capacity can be automatically supplied during periods of dehumidification or significant snow accumulation.

Ventilation

A large number of ventilation functions (not discussed here) are associated with the control of temperature, using various combinations of side and ridge vents. Ventilation in forest nurseries consists generally of a series of staged on/off functions (e.g., different combinations of numbers of fans and fanspeeds). The ventilation setpoints can be specified according to time of day, ambient light level, or distance (in degrees) to the heating setpoint(s). In staged or cascaded ventilation, each stage has a separate temperature setpoint.

Cooling

Cooling functions are staged (for instance, supplying water to evaporative cooling pads) and can be simply an extension of the previously noted ventilation functions. However, cooling devices like fog nozzles can be pulsed, with control over the interval and pulse length. Setpoints are handled in a manner similar to ventilation.

Humidity Control

In a forestry context, humidity control usually means dehumidification. Moderate ventilation in conjunction with increased heating (to maintain set temperature) is possible. Alternatively, humidity may be decreased by increasing the set temperature slightly without venting (useful when supplemental CO_2 is used). Conversely, it is possible to allow the set temperature to decrease by a preset number of degrees while venting occurs to conserve energy. To increase relative humidity, temperature may be lowered slightly, or misting or fogging systems can be pulsed on and off at programmable time intervals. Multiple humidity setpoints over a 24 h cycle are possible, with ramping between them. Setpoints can also be made responsive to light levels or dewpoint in the greenhouse (for pollination or possibly inhibition of fungal growth).

Irrigation

Automatic irrigation can be performed at specified times of day, at programmed intervals between specific times, or based on light intensity (dawn-dusk), after a set amount of accumulated radiation (light integral), or in response to an external device (artificial leaf, flat weight, etc.). Each growing zone can be independently controlled by altering the opening pattern of a matrix of solenoid or motorized valves. Duration of the irrigation period can be programmed and made sensitive to ambient light intensity. Where demand is not constant over time (for instance, if cycles overlap due to lengthening at high light), irrigation priorities may be assigned to different zones, to ensure adequate water in critical areas without exceeding the capacity of existing supply lines.

Fertility

Fertilizer mixtures can be supplied from stock solutions blended by opening solenoid valves in different combinations. Used in conjunction with the irrigation valves, different mixtures can be sent to various growing zones under programmed control. Rinse times can be added to flush the irrigation lines or wash the foliage. Fertilization can be performed automatically according to time of day, integrated values of light, or according to external (keyboard) command. To avoid foliar burn, a weaker solution can be applied at light levels which exceed a pre-set intensity.

Shading

One or more layers of shade cloth can be deployed and retracted in response to either outside light and/or temperature conditions, or inside temperature. Preset timing for shading is also possible, as is periodic

shading within a defined range of radiation where, for example, 10 minutes of shade within a 30 minute period can be specified between two light levels. By pulsing the shading curtains (or using a position sensor), the maximum partial deployment of the curtain(s) can be defined anywhere between 0 and 100 percent. Because shading is a versatile method of controlling not only light levels, but other greenhouse environmental parameters as well (humidity, energy conservation), there can be interaction between a shading program and setpoint values defined for other purposes. For instance, shade curtains can be forced to close below a certain temperature, which could have value in the event of heating system failure or perhaps for frost protection in an unheated greenhouse.

Photoperiod (Blackout) and Energy Conservation

Photoperiod and shading functions are closely related and the controlling factors are similar. Blackout curtains, although generally run to impose short-day conditions, are also useful for energy conservation. For night use, deployment can be based on outside light levels falling below (at dusk) and rising above (at dawn) set point values to maximize energy conservation by ensuring that the curtains are drawn whenever light levels fall below useable values. The number of minutes before sunset and after sunrise can also be chosen which will also operate the curtains in a fashion analogous to using light levels. The computer stores daylength information (based on the geographic latitude of the nursery location) and thereby automatically recalculates the occurrence of dusk and dawn each day. There can also be different curtain opening strategies. The occurrence of moisture (using a rain sensor) coupled with outdoor temperature below freezing will be interpreted as snowfall, prompting retraction to prevent snow accumulation on the cover. Opening can also be pulsed to prevent the downwash of cold air which accumulates between the curtain and the cover. Pulse length and interval may be timed or alternatively may stop if the drop in temperature exceeds a specified tolerable limit.

Supplementary Carbon Dioxide Control

One or more small infrared gas analyzers may be connected to the computer to measure and control CO2 levels. Increased gas concentrations are provided through burning propane or kerosene, or by injection of compressed gas from bulk tanks. A minimum daytime concentration can be specified below which CO2 is to be added. This setpoint can be made to increase according to the ambient light level, and decrease when the light integral exceeds a specified value (if required). Whether any addition occurs at all can be a function of time or minimum ambient light level. Addition can be halted during periods of venting, and restarting can be delayed for a specified period of time to prevent wasteful consumption during periods of continuous or intermittent ventilation. However, if elevated CO2 levels are required even during venting, the setpoint for addition can be lowered depending on the amount of ventilation taking place (used primarily in greenhouses with continuously adjustable venting systems). Conversely, the setpoint temperature for venting can be programmed to increase as a function of CO2 concentration.

Supplementary (Photoperiodic and Assimilation) Lighting

Both types of lighting can be programmed to start and stop on the basis of clock time, ambient light level, or the time interval since dusk or prior to dawn. If ambient light level is selected, it is possible to modulate the setpoint values according to the previous day's integrated light total. Alternatively, assimilation lighting may be stopped when the light integral for (day + supplementary light) total reaches a specified value.

Alarms

For each greenhouse zone or compartment, alarms can be set for most of the above functions. The priority can also be indicated, which allows those alarm functions deemed critical (heating, cooling) to actually activate some warning device (for instance, a buzzer or automatic telephone dialer) whereas the deviation of other functions will only be recorded on a printout. Most alarms can be turned on and off independent of one another.

Weather Station

In order to respond interactively with the outside climate, a small weather station is included with most computer systems. Light intensity, temperature, relative humidity, windspeed, and precipitation are recorded at frequent intervals (seconds or minutes). The computer system then uses these values to update and change, if necessary, the setpoint values for the control regimes in all zones. The weather station is usually regarded by the computer simply as another zone within which measurements but no controlling functions occur. Weather data are retained and recorded in a fashion similar to any other zone, allowing subsequent retrieval and use for correlating with, for example, crop growth curves. Note that weather data can be used directly to implement functions like spraying for frost protection in an adjacent holding area.

Datalogging

Routine data acquisition is a standard feature. The data are collected from all zones during every scan. Data are stored and averaged for a selectable period of time (hourly, every 4 h, daily, etc.). The means, maxima and minima are then formatted into a file and placed on the computer's storage medium (diskette, tape, or hard disk). A menu-driven program is used to retrieve and display the data in the form of a graph of one or more variables plotted as a function of time - similar to reading a hygrothermograph chart except that the graphs, numeric averages, and other data may be displayed onscreen, printed out, or both.

Computer/Equipment Interface

In a greenhouse computer system, the interface is both the process by which the computer programs are translated into real-time events occurring in the greenhouse and the box(es) or cabinet(s) where sets of wiring leading from the computer are physically and electronically joined

to sets of wiring from the various peripheral devices. Careful consideration should be given to this seemingly innocuous part of the computer system for several reasons:

- You may decide to cut costs by making your own interface cabinet on site rather than buying one from the computer manufacturer. How well the cabinet is designed will determine how easily the computer can be hooked up to the existing greenhouse equipment.

- If the company provides the interface, their design may determine whether future wiring changes can be done without having to call upon outside technicians to do the job.

- The interface cabinet is an obvious place to perform diagnostic tests. Problems may occur in three areas: the greenhouse equipment, the A.C. power supply, or the low voltage signal sent from the computer. Being able to reach testpoints for all three items in one spot is an clear advantage.

The prototype interface cabinets, which were designed for the greenhouses at Acadia FES, are shown in Figure 2(a). Although design improvements must still be made, the cabinets have the following advantages:

- They are small (1m x 1m), waterproof enclosures intended for placement within the greenhouse itself. As a result, when switches are toggled, greenhouse equipment can actually be observed to be working.

- Electrical connections for every device in the greenhouse are brought back to three busses in the cabinet (Fig. 2(b)), allowing connections to be altered and added easily.

- Each greenhouse device has a separate circuit breaker and switch set (Fig. 2(b)). Where a single device has more than one function, such as a two-speed fan, a separate circuit is included for each speed.

- The switch set for each device consists of three separate switches: manual operation, automatic operation (for use with, for instance, a timer), and computer control where a relay can be toggled. Operational experience has shown that the automatic mode is seldom used and is probably unnecessary. Manual switching is a direct electrical connection for use either in emergencies, as a diagnostic tool (to detect equipment failure), or for routine tasks which are not computer programmable (e.g., fungicide application).

- An A.C. indicator light in the cabinet directly in line with each device illuminates to show that A.C. power is actually being provided. (For example, if the light is on and the device is not, it can indicate that a motor has burned out.) The circuit breakers and all switches light up when turned on so that the mode (manual, automatic, computer) and presence of A.C. power are quickly visible, even at night.

- All the relays which connect the computer to the greenhouse devices are in the same cabinet, along with spares mounted on the backplane (to allow quick testing and substitution), and spots for future additions (Fig. 2(c)).

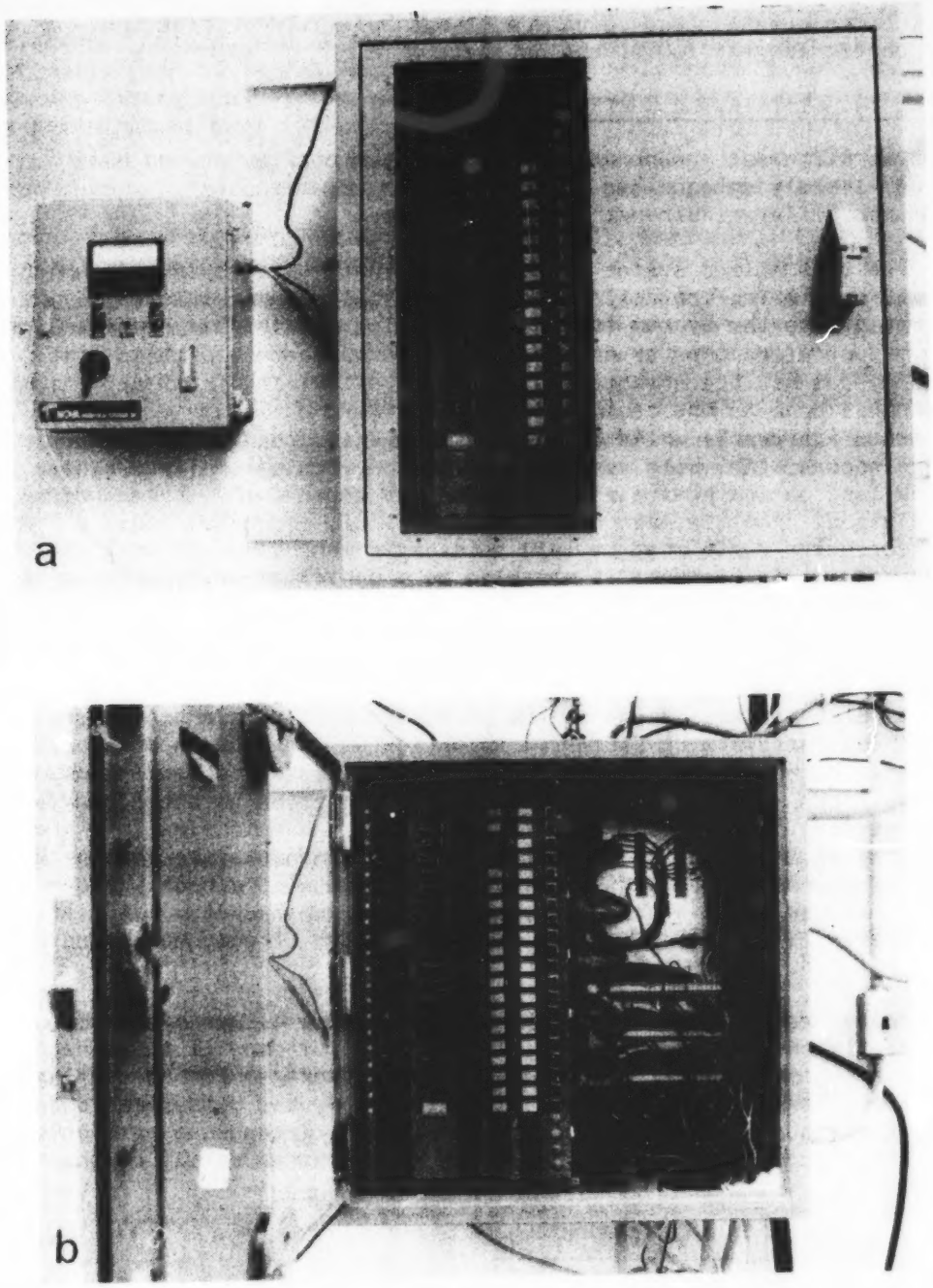

Figure 2. An interface cabinet at Acadia FES: (a) the waterproof cabinet with switches visible through the door; (b) interior showing the breaker/switch/indicator panel on the left and connecting busses on the right.

Whether a large, central, interface cabinet or smaller units in each greenhouse are chosen, the design is important. If a turnkey system is being provided by the greenhouse computer supplier, it is especially important to question the company at length on the specifications for their particular version of the cabinet.

CENTRAL VS. DISTRIBUTED CONTROL

Two different greenhouse computer system configurations have evolved, loosely categorized as "central" or "distributed". Each type of system has different strengths and weaknesses.

The centralized system has one central microprocessor unit which does all monitoring/control. A "dumb" terminal with a keyboard may be integrated into the system (analogous to using a mainframe computer) or an accessory microcomputer may be used to communicate with this unit. Such a system has the advantage of bringing all wiring from many greenhouses back to one central point, and there are fewer electrical components (hardware) which can potentially fail, though if electronic failure occurs, the whole system is affected. The centralized system becomes less economic with a large number of greenhouses spread out at some distance from the main console, since long, expensive runs of multi-conductor cable must be laid to every greenhouse. If only one microprocessor is present, it may also be a dedicated unit, meaning it cannot be used for any other purpose.

A distributed system uses many small microprocessors (one for every one or two greenhouse zones) connected in a network with a central console which is usually one of the popular brands of microcomputer. The programming (software or firmware) which actually runs each greenhouse resides in each of the distributed units. The central console communicates with the satellite units to provide information to their programs and to receive information for datalogging. Since communications are done using RS-232, cabling costs to distant greenhouses are cheaper and, if one of the satellite units fails, only the zone(s) directly under the control of that unit is(are) affected, not the whole system. A distributed system is more complex with a larger number of components and will, therefore, require more maintenance.

The microcomputer used for communications in either system should be carefully specified and the supplier should informed if it is required to perform other nursery functions. Software packages for accounting, crop record keeping, etc. should be considered by the nurseryman beforehand. Assurances should be sought that both the greenhouse environmental control software and other programs will run together easily on the same system.

CAVEAT EMPTOR - LET THE BUYER BEWARE

The greenhouse environmental computer market is still in flux. New companies appear regularly to compete with more established firms and all firms are struggling to incorporate the latest improvements in

microcomputer technology into their products. Before selecting a system, it is important to ask "Will the company form which you are purchasing a 'bargain' computer package be in business next year?" A higher initial cost may be incorporating the extra development costs incurred by the manufacturer to ensure that their product has sufficient quality and after-sales support to remain in the marketplace for some time. At this stage of climate control computer systems development, the nurseryman only gets what he pays for.

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